A 65 m diameter full-steerable radio telescope TMRT with the frequency coverage from 1.25 to 50.0 GHz is newly built at Shanghai. To satisfy the demands of the pulsar and spectral line observations, a Digital Backend System (DIBAS) was built for this telescope. The DIBAS can support both the pulsar search and online folding pulsar observation. Either the coherent or incoherent dedispersion pulsar observation mode can be chosen according to demand of observers. The testing pulsar observation results showed that the pulsar observation system works well. A series of pulsar projects (such as pulsar timing, hunting, VLBI, etc) are carried out with the TMRT. Some important findings are expectable in the future.

2 The pulsar observation system

2.1 The receivers of TMRT

The TMRT is a newly built 65 m diameter fully-steerable radio telescope located in the western suburbs of Shanghai, China. This telescope is designed to cover the frequency ranging from 1.25 to 50.0 GHz using 7 sets of cryogenically cooled receivers. The construction of TMRT was divided into two stages. The first stage of construction was finished with the equipment of four low frequency receivers in December 2013. The second stage was finished at the end of 2016. The highest working frequency of the TMRT was upgraded to 50 GHz. And the active surface control, which was used to compensate for gravity deformation of the main reflector during tracking, also started to work at the second stage. Taking the power law spectra of pulsar radiation into consideration, we will pay more attention on the detail parameters of four low frequency receivers usually used in pulsar observations, and a comparison of the capability with other large fully-steerable telescopes. We calculate the system equivalent flux density SEFD = 2kBTsys/Ae which is a parameter taking the system temperature Tsys and the effective aperture Ae into consideration. The SEFD and frequency range Freq-R of these antennas are presented in table 1. From this table, it can be seen that the TMRT has comparative sensitivity as the other large telescopes in the world. Especially at C band, the TMRT has its advantages because of its wide band width and low system temperature.

2.2 The backend systems of TMRT

A Digital Backend System (DIBAS) was built for the TMRT to satisfy pulsar and spectral line observation demand-
Table 1. The parameters of low frequency receivers of the TMRT and other fully-steerable large telescopes

<table>
<thead>
<tr>
<th></th>
<th>GBT (100 m)[4]</th>
<th>Effelsberg (100 m)[5]</th>
<th>Parkes (64 m)[6]</th>
<th>Lovell (76 m)[5]</th>
<th>TMRT (65 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Freq – R (GHz)</td>
<td>1.15-1.73</td>
<td>1.27-1.45, 1.59-1.73</td>
<td>1.2-1.8</td>
<td>1.25-1.50, 1.55-1.73</td>
</tr>
<tr>
<td></td>
<td>SEFD (Jy)</td>
<td>10</td>
<td>20,19</td>
<td>31</td>
<td>36,65</td>
</tr>
<tr>
<td>S</td>
<td>Freq – R (GHz)</td>
<td>1.73-2.6</td>
<td>2.20-2.30</td>
<td>2.2-2.5</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>SEFD (Jy)</td>
<td>12</td>
<td>300</td>
<td>25</td>
<td>–</td>
</tr>
<tr>
<td>C</td>
<td>Freq – R (GHz)</td>
<td>3.95-5.85</td>
<td>5.75-6.75</td>
<td>4.5-5.1</td>
<td>6.0-7.0</td>
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<tr>
<td></td>
<td>SEFD (Jy)</td>
<td>10</td>
<td>25</td>
<td>61</td>
<td>80</td>
</tr>
<tr>
<td>X</td>
<td>Freq – R (GHz)</td>
<td>8.00-10.1</td>
<td>7.9-9.0</td>
<td>8.1-8.7</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>SEFD (Jy)</td>
<td>15</td>
<td>18</td>
<td>170</td>
<td>–</td>
</tr>
</tbody>
</table>

Figure 1. The block diagram of the DIBAS

The DIBAS is based on a Field Programmable Gate Array (FPGA) frontend and a heterogeneous computing backend comprised of Graphical Processing Units (GPUs) and x86-64 CPUs [2]. To save the developing time, the DIBAS is built by importing pulsar observation mode into the design of Versatile GBT Astronomical Spectrometer (VEGAS) which is developed with the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) technology [1, 10]. For the pulsar observation modes, DIBAS can provide much the same capabilities as Green Bank Ultimate Pulsar Processing Instrument (GUPPI) [11]. The block diagram of DIBAS is shown in Fig 1.

At present, our DIBAS system consists of three pairs of analog to digital converters and three pieces of corresponding Roach-II electronic boards which can work separately. Both pulsar searching mode and on-line folding mode are supported by the DIBAS. Either the coherent or the incoherent dedispersion observation mode can be chosen according to demand of observers. In the coherent dedispersion observation mode, GPUs on the 8 High Performance Computers (HPCs) are used to satisfy the intensive computation demand. The total observation bandwidth is divided into 8 sub-band. The data from each sub-band will be transferred onto the corresponding HPC with the 10 GbE connection. Each HPC does the assigned coherent dedispersion calculation on the data from the related sub-band. For the incoherent dedispersion observation mode, the maximum input bandwidth of each digitizer channel is up to 2 GHz. Since three pairs of digitizer (one digitizer for each polarization) are currently available, a maximum bandwidth of 6 GHz can be supported. For the coherent dedispersion observation mode, the maximum bandwidth is 1 GHz which is limited by the computing power of the current HPCs.

For the online folding pulsar observation mode, the DIBAS will record the full Stokes-parameters. Either the full Stokes-parameters or the total power (I-only) parameters can be recorded in the pulsar search observation mode according to the demand of observers. The final pulsar observation data is written out in 8-bit PSRFITS format [3]². In order to satisfy the high data recording rate demand, the Lustre file system with the size of 80 T is adopted to do the online observation data recording. This file system can make sure the possibility of recording pulsar searching observation data with time resolution as high as 40.96 μs.

3 The pulsar observation projects and some results

Extensive testing observations have been made on the pulsar observation system of the TMRT. It is indicated that the TMRT pulsar observation system works very well. The observation results on the PSR B1937+12 obtained with the coherent dedispersion and incoherent dedispersion online folding observation mode are shown in Fig 2. P-SR B1937+21 is a millisecond pulsar with the rotation period of 1.56 ms. The dispersion measure and the flux density at 1.4 GHz is 71.0237 cm³pc and 13.2 mJy respectively [9]. The observation was carried out at the wavelength of 21 cm (L-band). The total bandwidth is divided into 1024 channels in both observations. These two observations were

Figure 2. Integrated profiles of PSR B1937+21 with coherent and incoherent dedispersion online folding observation mode

also carried with the same observation length (10 min). The coherent and incoherent observation results are normalized and plotted in red and blue solid line with 1024 bins respectively. By comparison, a much narrower profile with fine structure is obtained with coherent dedispersion observation mode, as this mode can eliminate dispersion effects completely.

According to our TMRT pulsar system parameters and test results, we are making some practical pulsar observation projects. A list of these pulsar projects will be presented in the following part.

- Long term pulsar timing: We are monitoring the timing properties of about 100 pulsars. These pulsars are chosen carefully from the pulsar catalogue database. Each of them has special timing properties. Ten of these pulsars are millisecond pulsars. Some of pulsars show glitch phenomena. Some of them are located in special place such as around the Galactic center. The C-band is the first choice of the observing frequency on these pulsars. If the pulsar is too weak to detect at C-band, we will move to L-band. We make sure at least one round of timing observation on each pulsar in our sample per month.

- Multi-frequency observation and radiation mechanism: We are taking advantage of our wide frequency coverage receivers to measure the multi-frequency integrated profile, flux density and polarization properties of tens of pulsars to study their radiation mechanism. Taking a small research subject that we have just finished now, we obtained the profiles and flux density of 11 pulsars with the TMRT for the first time at 8.6 GHz. The radiation location and particle energy of PSR B1133+16 were confined in accordance with the multi-frequency radio profiles obtained with the TMRT and other telescopes [7].

- Single pulse properties of pulsars: We are studying the single pulse properties of tens of pulsars. These pulsars show different properties, such as nulling, subpulse drifting, giant pulse, etc. By the single pulse analysis on the magnetar PSR J1745-2900 in the Galactic center, we characterize its bright pulsar bursts which are different from the giant pulse [12].

- High frequency pulsar hunting: As we have no multi-beam receiver which is suitable for pulsar hunting, we choose some special areas to do pulsar search, such as Galactic center, unassociated γ-ray point sources and globular clusters. Our pulsar hunting will be carried out at C- or X-band. Though the pulsar shows the power law spectra property, high frequency pulsar hunting also has some advantages, such as more transparent to the thick plasma around the Galactic center, lower galactic noise background, weaker dispersion, smaller scattering and less scintillation.

- Pulsar observation with VLBI: Pulsar astrometry with VLBI can measure the model independent distance and proper motion parameters of the pulsar, which are important for studies of the pulsar evolution, interstellar medium, etc. For pulsars located at high declination (DEC>45 deg), the resolution in right ascension (RA) will be affected because of the limited length of projected baseline along East-West direction of the Very Long Baseline Array (VLBA). The participation of TMRT will be able to lengthen the baseline twice times in East-West direction and improve the UV-coverage of observation of source very much (see Fig 3). We are carrying out Pathfinder observations on 2 high declination pulsars in cooperation with the National Radio Astronomy Observatory (NRAO), Cornell University and Swinburne University. The Chinese Data Acquisition System (CDAS) and the Mark 5B are used to do the data sampling and recording at the TMRT station. We chose the 2 Gbps observation mode at L-band. This is the highest data recording rate of the VLBA and TMRT. It is indicated by the preliminary data analysis that we have detected these two pulsars successfully. In the following, we are planning to propose further joint observations of more pulsars.

In conclusion, high sensitivity and stable pulsar observation system has been built up at the TMRT. The pulsar will be one of important scientific research targets of the TMRT. Some tentative pulsar observations with the TMRT have been done. And good observation results have been obtained. The TMRT is carrying out a series of pulsar observation project. Some important findings can be expected in the following pulsar studies with the TMRT.
4 Acknowledgements

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